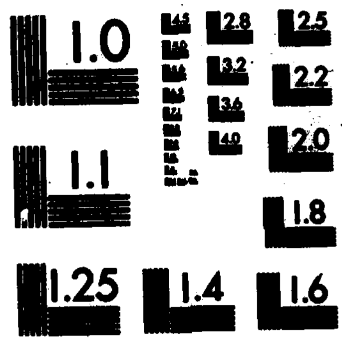
AD-A122 119 THE PERFORMANCE OF A TRIPOLE ADAPTIVE ARRAY AGAINST CROSS-POLARIZED JAMMING(U) OHIO STATE UNIV COLUMBUS ELECTROSCIENCE LAB R T COMPTON OCT 82 ESL-713603-8 N00019-81-C-0093 1/1

UNCLASSIFIED F/G 17/4 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(12)

OSU

The Ohio State University

AD A122119

THE PERFORMANCE OF A TRIPOLE ADAPTIVE ARRAY AGAINST CROSS-POLARIZED JAMMING

R.T. Compton, Jr.

The Ohio State University

ElectroScience Laboratory

Department of Electrical Engineering
Columbus, Ohio 43212

Technical Report 713603-8
Contract No. N00019-81-C-0093
October 1982

Naval Air Systems Command
Washington, D.C. 20361

NOTICES

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2. AD-A122 119	3. Recipient's Accession No.

4. Title and Subtitle
THE PERFORMANCE OF A TRIPOLE ADAPTIVE ARRAY AGAINST CROSS-POLARIZED JAMMING

5. Report Date
October 1982

6.

7. Author(s)
R.T. Compton, Jr.

8. Performing Organization Rept. No.
ESL-713603-8

9. Performing Organization Name and Address
The Ohio State University ElectroScience Laboratory
Department of Electrical Engineering
Columbus, Ohio 43212

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No
(C)
(G) N00019-81-C-0093

12. Sponsoring Organization Name and Address
Naval Air Systems Command
Washington, D.C. 20361

13. Type of Report & Period Covered
Technical Report

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report discusses the performance of an adaptive array using three mutually perpendicular dipoles (a "tripole") against a cross-polarized jamming signal. The jamming consists of two statistically independent signals transmitted on orthogonally polarized antennas. It is shown that the adaptive array is least susceptible to such jamming if the desired signal is circularly polarized. It is most susceptible if the desired signal is linearly polarized.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED	Unclassified	16
	20. Security Class (This Page)	22. Price
	Unclassified	

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION

In a previous paper [1], the author discussed the performance of an adaptive array consisting of three mutually perpendicular short dipoles at the same center (a "tripole"). The purpose of that study was to illustrate what may be accomplished by an adaptive array that adjusts to signal polarization as well as angle of arrival. The performance of the tripole was examined when the array receives a desired signal and one interference signal, each with an arbitrary elliptical polarization.

The purpose of the present report is to broaden the study in [1] by examining the performance of this array when the interference is a cross-polarized jammer, i.e., one that consists of two independent signals transmitted on orthogonal polarizations from the same site. Such a jammer is of interest because, as shown in [1], as long as the desired signal is not linearly polarized, the tripole effectively eliminates a single interference signal, regardless of its arrival angle or polarization. The only exceptions are when the interference arrives from the same direction and has the same polarization as the desired signal and when it arrives from the opposite direction with conjugate polarization. Hence, to increase its effectiveness, a sensible strategy for a jammer is to transmit two independent signals on orthogonally polarized antennas. Such jamming uses up to two degrees of freedom in the array and makes it more difficult for the array to protect the desired signal.

In this report, we discuss the performance of the tripole against such a jammer. We shall follow the notation and definitions used in [1] throughout, so the reader may wish to refer to that paper before reading this report.

II. FORMULATION

Consider an adaptive array using three mutually perpendicular short dipoles (a "tripole") as shown in Figure 1. Assume a CW desired signal arrives from direction (θ_d, ϕ_d). (θ and ϕ are defined in Figure 1). Suppose the desired signal has an arbitrary elliptical polarization specified by an ellipticity angle α_d and an orientation angle β_d, as defined in [1]. The desired signal vector in the array is then

$$X_d = A_d\, e^{j(\omega t+\psi_d)} U_d \quad , \tag{1}$$

where A_d is the signal amplitude, ω is the frequency, t is the time, ψ_d is the carrier phase angle, and U_d is a vector containing the arrival angle and polarization parameters [1, Equation (12b)]

$$U_d = \begin{pmatrix} \sin\gamma_d \cos\theta_d \cos\phi_d\, e^{j\eta_d} - \cos\gamma_d \sin\phi_d \\ \sin\gamma_d \cos\theta_d \cos\phi_d\, e^{j\eta_d} + \cos\gamma_d \sin\phi_d \\ -\sin\gamma_d \sin\theta_d\, e^{j\eta_d} \end{pmatrix} \quad . \tag{2}$$

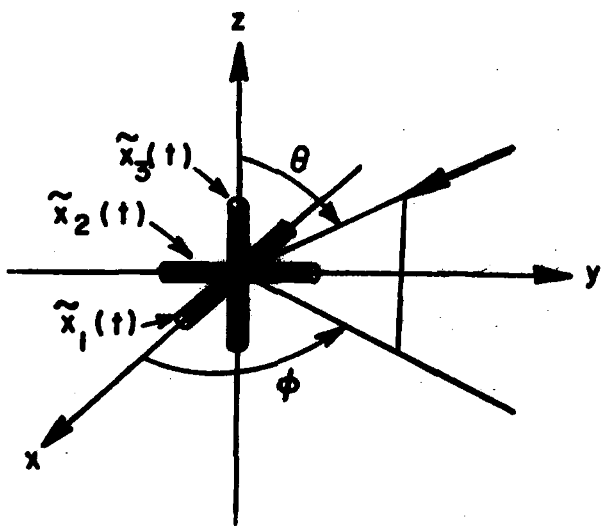


Figure 1. Tripole antenna.

Here γ_d and η_d are angles related to α_d and β_d by [1]:

$$\cos 2\gamma_d = \cos 2\alpha_d \cos 2\beta_d \quad , \tag{3}$$

$$\tan \eta_d = \tan 2\alpha_d \csc 2\beta_d \quad . \tag{4}$$

We also assume ψ_d is a random variable uniformly distributed on $(0,2\pi)$.

Next, assume a jamming signal arrives from direction (θ_i, ϕ_i). Suppose this jamming signal has been generated by transmitting two statistically independent signals of equal power on cross-polarized transmitting antennas. Specifically, let us suppose the jamming consists of a signal $\tilde{i}_1(t)$ with linear polarization in the $\hat{\theta}$-direction and another signal $\tilde{i}_2(t)$ with linear polarization in the $\hat{\phi}$-direction. An electromagnetic wave propagating into the array in Figure 1 with electric field components E_ϕ and E_θ has x, y, z-components

$$\begin{aligned}\overline{E} &= E_\phi \hat{\phi} + E_\theta \hat{\theta} \\ &= (E_\theta \cos\theta \cos\phi - E_\phi \sin\phi)\,\hat{x} \\ &\quad + (E_\theta \cos\theta \sin\phi - E_\phi \cos\phi)\,\hat{y} \\ &\quad - (E_\theta \sin\theta)\,\hat{z} \quad .\end{aligned} \tag{5}$$

Hence, the $\hat{\theta}$-component of the jamming will produce an electric field

$$\overline{E}_1 = \tilde{i}_1(t)\,[\cos\theta_i \cos\phi_i\,\hat{x} + \cos\theta_i \sin\phi_i\,\hat{y} - \sin\theta_i\,\hat{z}] \quad , \tag{6}$$

and hence a signal vector

$$X_1 = \tilde{i}_1(t)\ U_1 \quad , \tag{7}$$

where

$$U_1 = \begin{pmatrix} \cos\theta_i \cos\phi_i \\ \cos\theta_i \sin\phi_i \\ -\sin\theta_i \end{pmatrix} \quad . \tag{8}$$

Similarly, the $\hat{\phi}$-component of the jamming will produce a signal vector

$$X_2 = \tilde{i}_2(t)\ U_2 \quad , \tag{9}$$

with

$$U_2 = \begin{pmatrix} -\sin\phi_i \\ \cos\phi_i \\ 0 \end{pmatrix} \quad . \tag{10}$$

We assume that $\tilde{i}_1(t)$ and $\tilde{i}_2(t)$ are statistically independent, zero-mean, narrowband gaussian noise process, each with power p_i:

$$E\,[\tilde{i}_\ell^*(t)\ \tilde{i}_m(t)] = p_i\ \delta_{\ell m} \quad , \quad 1 < \ell, m < 2 \ , \tag{11}$$

where $\delta_{\ell m}$ is the Kronecker delta and * denotes the conjugate.

Before proceeding, we comment that the jamming signal described above (that is, with both the $\hat{\theta}$- and $\hat{\phi}$-components included) is what is known as a randomly polarized signal [2,3]. It has a state of polarization that varies randomly with time. A signal with a single, fixed elliptical polarization (including the special cases of linear and circular polarization), on the other hand, is said to be completely polarized [2]. The desired signal in (1) is an example of a completely polarized signal. In general, a randomly polarized signal may be decomposed into the sum of two independent, orthogonally polarized signals [2]. Any two orthogonal polarizations may be used in this decomposition. For convenience, we have chosen to define the jamming as the sum of linearly polarized $\hat{\theta}$- and $\hat{\phi}$-components. However, any other two orthogonal polarizations would do just as well. More importantly, it does not matter whether the cross-polarized antennas actually used to transmit the jamming are linearly polarized antennas aligned with the $\hat{\theta}$- and $\hat{\phi}$-coordinates or not. Transmission of two equal power, independent, jamming signals on any two orthogonal polarizations will result in a signal that is electrically equivalent to that defined above.*

Additionally, it is important to note that although the jamming signals $\tilde{i}_1(t)$ and $\tilde{i}_2(t)$ are assumed to have a nonzero bandwidth, their bandwidth plays no role in this problem. Since all three dipoles in

---

*If the two signals $\tilde{i}_1(t)$ and $\tilde{i}_2(t)$ have unequal power, the resulting jamming signal will be partially polarized [2]. In this case one must take into account the actual polarizations transmitted.

Figure 1 are located at the same center, there is no interelement time delay for the received signals $\tilde{f}_1(t)$ and $\tilde{f}_2(t)$. (For this reason, $\tilde{f}_1(t)$ and $\tilde{f}_2(t)$ may be written as scalar factors in the signal vectors, as we have done in Equations (7) and (9)). Most adaptive arrays have elements that are physically separated. Their separation causes the jamming to arrive with a different timing (dependent on arrival angle) in each element. This timing difference reduces the correlation between the jamming signals in different elements and makes it more difficult for the array to null the jamming. As a result, array performance usually drops with jamming bandwidth [4]. However, for the array studied here, there is no interelement time delay, regardless of signal arrival angle, so there is no performance degradation with bandwidth.**

Next, we assume the signal from the j^{th} array element also contains a zero-mean thermal noise voltage $\tilde{n}_j(t)$. We assume these noise voltages have power σ^2 and are statistically independent of each other:

$$E\,[\tilde{n}_\ell^*(t)\,\tilde{n}_m(t)] = \sigma^2\,\delta_{\ell m}\,,\quad 1 < \ell,\, m < 3\,. \tag{12}$$

Moreover, ψ_d, $\tilde{f}_1(t)$, $\tilde{f}_2(t)$ and the $\tilde{n}_j(t)$ are all assumed independent of each other.

**Of course, there may be a bandwidth degradation if the signal processing paths behind the three elements are not matched in amplitude and phase over the bandwidth. However, that problem is not peculiar to the array studied here.

The total signal vector is then

$$X = X_d + X_1 + X_2 + X_n \quad , \tag{13}$$

where $X_n = [\tilde{n}_1(t), \tilde{n}_2(t), \tilde{n}_3(t)]^T$ is the noise vector (T denotes the transpose). The covariance matrix is then

$$\Phi = E(X^* X^T) = A_d^2 U_d^* U_d^T + p_i (U_1^* U_1^T + U_2^* U_2^T) + \sigma^2 I \quad . \tag{14}$$

As in [1], we assume the reference signal $\tilde{r}(t)$ in the LMS feedback loops is a replica of the desired signal,

$$\tilde{r}(t) = A_r \, e^{j(\omega t + \psi_d)} \quad . \tag{15}$$

The reference correlation vector S [1, Equations (3) and (18)] is then

$$S = A_r A_d U_d^* \quad . \tag{16}$$

Given Φ and S, the steady-state weight vector may be computed from

$$W = \phi^{-1} S \quad , \tag{17}$$

and from W, the array output desired signal power P_d, interference power P_i and thermal noise power P_n may be found as follows:

$$P_d = \frac{1}{2} E \{|X_d^T W|^2\} = \frac{A_d^2}{2} |U_d^T W|^2 \quad , \tag{18}$$

$$P_i = \frac{1}{2} E \{|(X_1+X_2)^T W|^2\} = p_i[|U_1^T W|^2 + |U_2^T W|^2] \quad , \tag{19}$$

and

$$P_n = \frac{\sigma^2}{2} |W|^2 \quad . \tag{20}$$

The array output signal-to-interference-plus-noise ratio (SINR) is then given by

$$SINR = \frac{P_d}{P_i+P_n} \quad . \tag{21}$$

We have used these equations to compute the SINR of the tripole subjected to cross-polarized jamming. The results are discussed in the next section.

III. RESULTS

Before presenting specific curves, we first summarize the results. In general, one finds that the tripole is least susceptible to cross-polarized jamming if the desired signal is circularly polarized. A linearly polarized desired signal makes the array most susceptible to cross-polarized jamming. By "most susceptible", we mean that the array

output SINR will be low for the widest range of jammer incidence angles. One minimizes the range of incidence angles where the output SINR is low by using a circularly polarized desired signal.

This result occurs for the following reason. Suppose a linearly polarized desired signal arrives from some given direction. Imagine a plane passing through the center of the tripole and oriented perpendicular to the desired signal electric field. Then it was shown in [1] that a linearly polarized interference signal arriving from any direction in this plane with its electric field perpendicular to the plane will produce a low output SINR from the array. From this result it follows that a cross-polarized jamming signal arriving in this plane will also produce a low output SINR, because a cross-polarized jammer may always be decomposed into two linearly polarized signals, one with its electric field perpendicular to this plane and the other parallel to it. Thus, a linearly polarized desired signal makes the array vulnerable to cross-polarized jamming from a wide region of space. It turns out that use of a circularly polarized desired signal reduces this vulnerability.

Now let us illustrate these remarks. Figure 2 shows a typical set of curves of the output SINR from the array as a function of ϕ_i, for θ_d=90°, ϕ_d=45°, β_d=90° and θ_i=90°. All curves are for

$$\xi_d = \frac{A_d^2}{\sigma^2} = 0 \text{ dB}$$

and

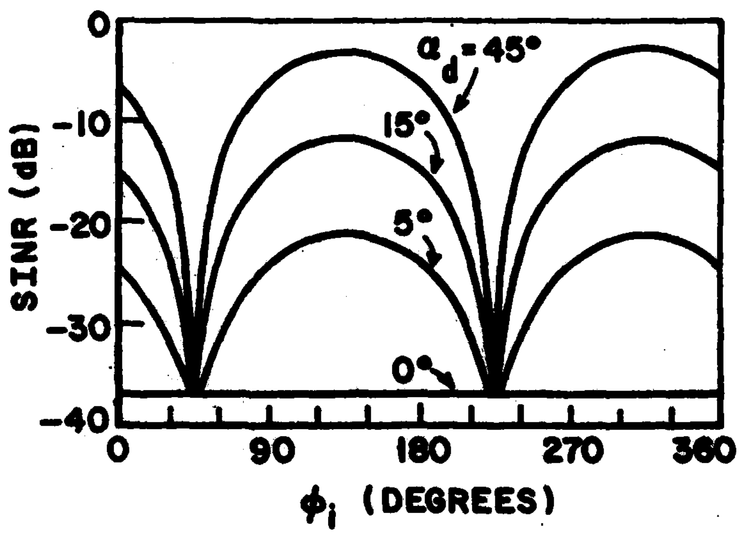


Figure 2. Output SINR vs. ϕ_i
θ_d=90°, ϕ_d=45°, β_d=90°, θ_i=90°
SNR=0 dB, Total INR=40 dB.

$$\xi_i = \frac{2p_i}{\sigma^2} = 40 \text{ dB} .$$

(ξ_d is the input desired signal-to-noise ratio [1] and ξ_i is the total input jammer-to-noise ratio, with both jammer components included.) Figure 2 shows the SINR for α_d=45°, 15°, 5° and 0°. (α_d is the ellipticity angle [1]. α_d=45° is circular polarization and α_d=0° is linear polarization. α_d=15° and 5° are elliptical polarizations in between.)

These curves illustrate the general result stated above. With a circularly polarized desired signal (α_d=45°), the jamming causes a low SINR only when ϕ_i is near 45° or 135°, i.e., when the jamming arrives from the same direction as, or the opposite direction to, the desired signal. However, as the desired signal polarization approaches linear, the array becomes less able to maintain the SINR for other values of ϕ_i. When the desired signal is linearly polarized, the jamming causes a low SINR for all ϕ_i.

In this example, the reason for this behavior is easy to see. With θ_d=90°, α_d=0° and β_d=90°, the desired signal has only a z-component of electric field at the tripole. With the jamming also arriving in the θ_i=90° plane (the plane perpendicular to the desired signal electric field), the z-component of the jamming is uncorrelated with the x- and y-components. The array cannot use the x- or y-components of the jamming to cancel the z-component. As a result, the array simply turns off the x- and y-axis dipoles and accepts the SINR that exists on the

z-axis dipole. (This SINR is -37 dB, because the z-axis dipole receives half the total jammer power.)

This example is a particularly simple case, because the desired signal electric field is parallel to the z-axis dipole. Cross-polarized jamming arriving from anywhere in the θ_i=90° plane will cause a low SINR. However, the same behavior occurs whenever the desired signal is linearly polarized, regardless of whether its electric field is parallel to one of the dipoles or not. Whenever the jamming arrives in the plane passing through the center of the tripole and oriented perpendicular to the desired signal electric field, a low SINR results.

In general, a circularly polarized desired signal makes the array least vulnerable to cross-polarized jamming, i.e., the range of jammer angles where the SINR is low is minimized. Figures 3 and 4 illustrate this result. They show all jammer arrival angles θ_i, ϕ_i for which the SINR exceeds -10 dB. In Figure 3 the desired signal is linearly polarized and in Figure 4 it is circularly polarized. These plots are again for ξ_d=0 dB and ξ_i=40 dB. With these values, the maximum possible output SINR is 0 dB and the lowest output SINR is -37 dB. Thus, the shaded regions in Figures 3 and 4 are the regions where the array yields at least 27 dB of protection.

In Figure 3 (linear polarization) the desired signal arrives from θ_d=ϕ_d=45°. Figures 3a, 3b, 3c and 3d show the SINR for four different values of β_d: 0°, 30°, 60° and 90°. (β_d is the polarization ellipse orientation angle [1]; it specifies the direction of the electric field.

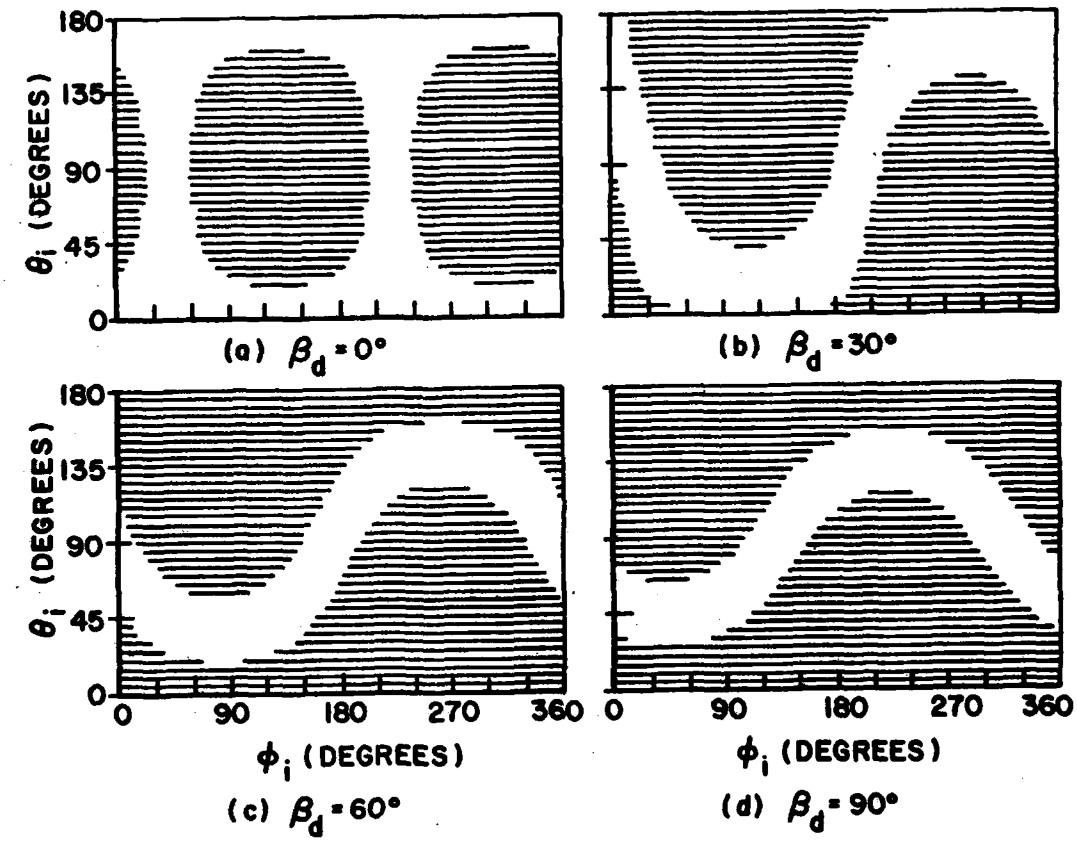


Figure 3. Jammer arrival angles where SINR > -10 dB. θ_d=45°, ϕ_d=45°, α_d=0° SNR=0 dB, Total INR=40 dB. (SINR > -10 dB in shaded region.)

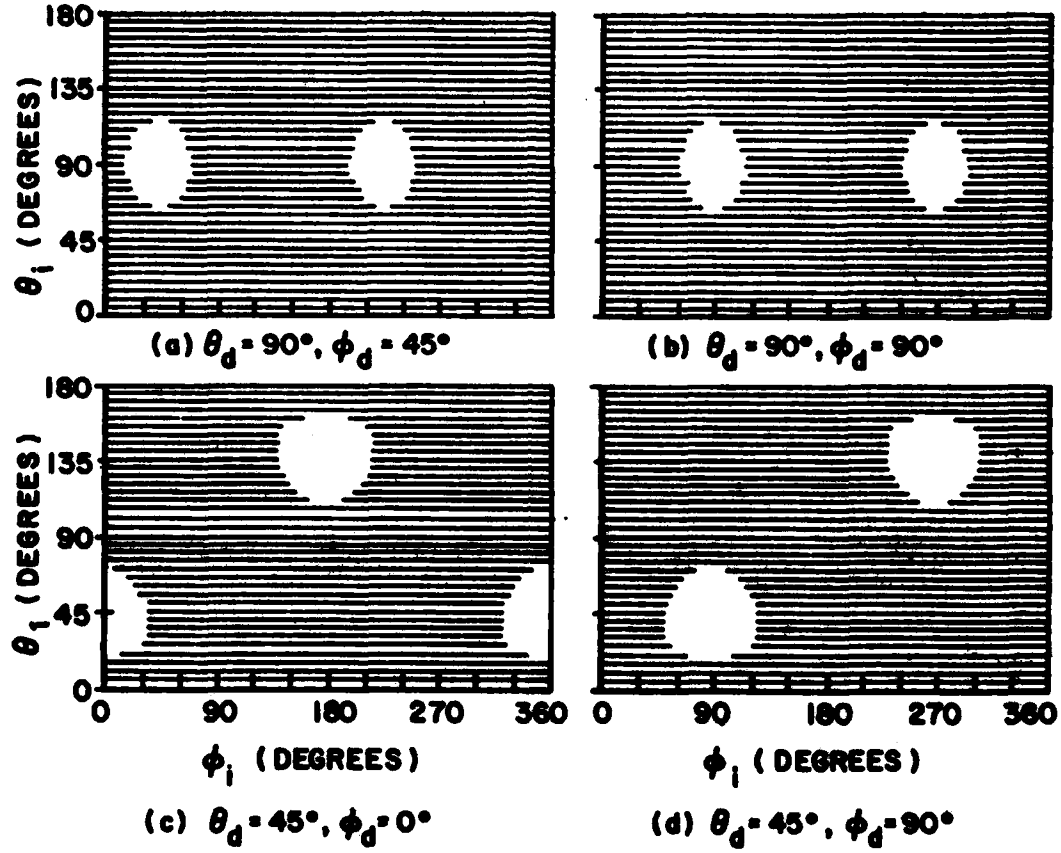


Figure 4. Jammer arrival angles where SINR > -10 dB. α_d=45° (β_d=0°), SNR=0 dB, Total INR=40 dB. (SINR > -10 dB in shaded region.)

For $\beta_d=0°$, the electric field is in the xy-plane in Figure 1. For $\beta_d=90°$, the electric field is in the z-direction.) It may be seen that there are many directions θ_i, ϕ_i from which the array can be jammed.

Figure 4 (circular polarization) shows similar results for four different desired signal arrival angles, as marked on the figures. Comparing Figures 3 and 4 shows that the array is vulnerable to cross-polarized jamming from a much smaller region of space if the desired signal is circularly polarized. Specifically, the array is vulnerable to jamming only within a small solid angle around either the desired signal direction or the direction opposite to the desired signal. This conclusion holds regardless of the particular arrival angle chosen for the desired signal.

REFERENCES

[1] R.T. Compton, Jr., "The Tripole Antenna: An Adaptive Array with Full Polarization Flexibility", IEEE Trans. Antennas Propagation, Vol. AP-29, pp. 944-952, November 1981.

[2] M. Born and E. Wolf, Principles of Optics, Pergammon Press, Inc., New York, 1980; Section 10.8.

[3] H.C. Ko, "On the Reception of Quasi-Monochromatic, Partially Polarized Radio Waves", Proc. IRE, Vol. 50, pp. 1951-1957, September 1962.